DRL NO. 34

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SOLAR CELL MODULES WITH PARALLEL ORIENTED INTERCONNECTIONS

FINAL
TECHNICAL/COST REPORT

JPL CONTRACT NO. 954716
DRD NO. MA003

PREPARED FOR

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JET PROPULSION LABORATORY
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THE JPL LOW-COST SOLAR ARRAY PROJECT IS SPONSORED BY THE U.S. DEPARTMENT OF ENERGY AND FORMS PART OF THE SOLAR PHOTOVOLTAIC CONVERSION PROGRAM TO INITIATE A MAJOR EFFORT TOWARD THE LOW-COST SOLAR ARRAYS. THIS WORK WAS PERFORMED FOR THE JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY BY AGREEMENT BETWEEN NASA AND DOE.

PROJECT NO. 2311

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1.0 Summary

This report documents activities and pertinent results which have been obtained on JPL Contract 954716. This contract provided for delivery of 24 solar modules, half of which were to be 48 cells in an all-series electrical configuration and half of a 6 paralleled cells by 8 series cells. Upon delivery of environmentally tested modules to JPL, low power outputs were discovered. These low power modules were determined to have cracked cells which were thought to cause the low output power. The cracks tended to be circular or linear, which were caused by different stressing mechanisms. A subsequent contract amendment to the original contract was made to fully explore these stressing mechanisms. The contract amendment also provided for delivery of 36 cells with selected interconnect configuration and two additional modules. The series-parallel configuration modules were also changed to 4PX12S. Efforts were undertaken to determine the causes of cell fracture. This resulted in module design and process modifications, foremost among which was the decision to utilize a multiple back contact interconnect design. The design and process changes were subsequently implemented in production. Table 1 is provided as a summary of attributes of all modules shipped to JPL on this contract.

2.0 Technical Discussion

The total stress, which solar cells in the Motorola solar module are subjected to, is a combination of additive components. These stress components have origins inherent in the materials utilized, specific designs employed, and manufacturing tolerances. Since the magnitudes of these stresses vary widely with imposed conditions (e.g., ambient temperature and mount plane skewness), one must be alert to both their absolute magnitudes, as compared to yield and

TB010630335 (11/70)

TABLE I MODULE CONFIGURATION SUMMARY

MODULE DESCRIPTION	Mod. Serial Number	Number Back Contacts	Back Contact Size	Pan Type	Kapton Dia-phram	Cell Orien-tation	Testing Per JPL 5-342-1C*				Power (w)		Ship Date
							Temp. Cycle	Humi-dity	Mech Flex	Press	Initi-al	Final	
IPX48S	001	1	5/8Dia	Shallow	Yes	No	JPL	JPL	JPL	JPL	27.6	27.2	6/24/77
"	002	1	"	"	"	"	MOT	MOT	MOT	MOT	26.3	26.8	8/12/77
"	003	1	"	"	"	"	JPL	JPL	JPL	JPL	26.8	----	6/24/77
"	004	1	"	"	"	"	MOT	MOT	MOT	MOT	27.7	26.8	8/12/77
"	005	1	"	"	"	"	JPL	JPL	JPL	JPL	26.6	26.0	6/24/77
"	006	1	"	"	"	"	MOT	MOT	MOT	MOT	27.5	26.4	8/12/77
"	007	1	"	"	"	"	JPL	JPL	JPL	JPL	27.4	26.9	6/24/77
"	009	1	"	"	"	"	JPL	JPL	JPL	JPL	26.9	26.4	6/24/77
"	010	1	"	"	"	"	NO	NO	NO	NO	26.6	----	6/24/77
"	012	1	"	"	"	"	MOT	MOT	MOT	MOT	26.4	26.6	8/12/77
1PX48S	013	1	"	"	"	"	MOT	MOT	MOT	MOT	27.9	26.8	8/12/77
4PX12SW/TC	5359E	5	3/16Dia	Deep	No	Yes	NO	NO	NO	NO	21.4	----	11/10/78
4PX12S	5360E	5	3/16Dia	"	"	"	NO	NO	NO	NO	22.3	----	11/10/78
"	630E	1	1/4 Dia	"	"	"	MOT	MOT	MOT	MOT	23.6	22.1	12/22/78
"	631E	1	1/4Dia	"	"	"	"	"	"	"	20.1	17.3	12/29/78
"	632E	1	1/4Dia	"	"	"	"	"	"	"	18.0	16.2	12/29/78
"	928E	5	3/16 Dia	"	"	"	"	"	"	"	28.1	27.08	12/29/78
"	930E	"	"	"	"	"	"	"	"	"	27.8	26.8	12/29/78
"	933E	"	"	"	"	"	"	"	"	"	27.8	26.8	12/29/78
"	934E	"	"	"	"	"	"	"	"	"	27.6	26.9	12/29/78
"	926E	"	"	"	"	"	JPL	JPL	JPL	JPL	22.3	----	10/27/78
"	927E	"	"	"	"	"	"	"	"	"	20.0	----	10/27/78
"	929E	"	"	"	"	"	"	"	"	"	22.9	----	10/27/78
"	935E	"	"	"	"	"	"	"	"	"	19.2	----	10/27/78
"	936E	"	"	"	"	"	"	"	"	"	20.2	----	10/27/78
4PX12S	937E	"	"	"	"	"	"	"	"	"	22.2	----	10/27/78

*JPL - Tested at Jet Propulsion Laboratory
MOT - Tested at Motorola

ultimate strengths of each component material, and the degradative effects of cyclic stresses. Similar variances can be affected via design changes, and if prudence is not exercised when such changes are undertaken, a positive change in the module's inherent reliability may not be achieved.

2.1 Stress Environment

The major silicon stress inducement factor, in the Motorola solar module, is thermal elastic in nature. Other factors include manufacturing tolerances, material related variances, support plane tolerances, and environmental transients.

2.2 Probable Failure Modes

Two predominant silicon cell failure types were observed. They are 1) linear fractures, which coincide with crystallographic axes and 2) micro-cracks, which are generally circular in nature and would appear to be induced by cyclic forces. Dissimilarities observed between the two failure types do imply that their respective driving potentials (and constraints to free strain relieving) are significantly different. The linear fractures are a result of a combination of forces, which include those traceable to manufacturing variances, thermal elastic effects, and macroflextures at the module level. Non-thermal elastic effects provide the predominate driving force for such failure.

Micro-cracks were observed to have appeared and subsequently propogated, with cyclic thermal elastic inducements. These cracks are somewhat circular in configuration and, in general, ring the P^+ contact on the back side of the cell. Initiation and propogation of these cracks appear to also exhibit a threshold with respect to temperature.

2.3 Test Philosophy

The failure mechanisms, postulated, indicate a need for a combination of high stress and cyclic stress inducing test conditions. The two principal methods of inducing these stresses are thermal and mechanical. These types of testing will also aid in quantifying the fatigue life of other module components which are susceptible to cyclically induced stresses.

Both types of testing are under way, at the cell and module levels, with carefully controlled test vehicles. The high stress tests are of short duration, and thus results of this type of stress inducement are available in a shorter time frame. The results were utilized to screen alternative design candidates, that are subjected to the longer cyclic tests. The combined results will then be used to arrive at the final module configuration.

3.0 Cell Level Activities

Activities at the cell level were undertaken to determine if the present metallization pattern (front and back) establish any significant residual stress in the silicon wafer. The areas of possible concern are 1) the different percentages of metal coverage front and back, 2) texture etching and 3) the pre-ohmic openings in front surface dielectric layers. The cell is basically composed of a bi-material sandwich of silicon and Sn-Pb solder. Since the amount of front side solder differs from that of the back side, the internal (silicon) stress field requires a complex description. As a result, it was concluded that information should be of an empirical nature. Temperature shock was used to gain insight into this area. Samples were prepared at the following levels: starting silicon substrate, substrate with texture etched front surface, P^+ and

N+ diffusions, substrate with texture etch, diffusions and dielectric coating, substrate with texture etch, diffusions and dielectric coating with pre-ohmic area etched, and completed solar cell with metallization. Each test vehicle was subjected to temperature shock via alternately dipping them in LN_2 (-196C) and room temperature alcohol. This 220C temperature excursion was selected to obtain the initial high stress data. Caution must be exercised when drawing out conclusions from such testing in that new failure mechanisms, due to extreme temperature excursion, can occur. The major benefit of such testing is that several design alternatives can be ranked in relative ruggedness.

It was determined that each successive process step did impact the ability of the solar cell to withstand temperature shock. The largest loss in wafer strength was observed between pre-chmic etch and metallization, although it is not thought that the mechanical strength of the silicon substrate is impaired to the extent that marginally is a problem for thicknesses greater than 10 mils. This is an area which will become increasingly important as thinner substrates are utilized to process solar cells. These stresses are dependent on the exact process utilized.

4.0 Interconnect Level Activities

Interconnect level activities on this contract had the common concern of stress reduction. Additionally, one must be cognizant of the interconnect's contribution of series resistance, heat transfer, inherent reliability (electrical contact and path redundancy) and its producibility. Motorola has elected to concentrate on the flexible circuit (copper-Kapton) approach, due to its processibility in low and medium volumes.

The variations in back contact design are of two major

categories, single and multiple contacts. Figure 4.1 itemizes the various designs which have been tested to date. The single back contact (SBC) designs involve the determination of the solder joint diameter which is small enough to minimize silicon micro-fractures and yet large enough to maintain low solder stress levels for long solder fatigue life. Interconnect designs one through four in Figure 4.1 are representative of these test vehicles. Test results indicated that the .250" diameter back contact is the most desirable in terms of reducing silicon stresses during low temperature thermal shock. Reference Figure 4.2.

Multiple back contact (MBC) designs which have undergone initial low temperature (LN_2-RT Alcohol) thermal shock are listed in Figure 4.1, designs five through sixteen. Temperature shock results are presented in Figure 4.2. Two MBC designs have shown promise in the reduction of silicon cell fractures. They are design numbers 07 and 16. These are shown in Figures 4.3 and 4.4. Design 16 has been chosen for production purposes, due in part to its ability to minimize power loss if cell breakage should occur within the module.

5.0 Module Level Activities

Module level activities have centered about methods of reducing encapsulation related cell stresses, increasing module-to-module uniformity (Reference earlier Contract reports for details), and verification of cell and interconnect level design hopefuls. These activities have resulted in increased levels of product uniformity and a lowered internal stress environment for the cells. A total of 30 experimental modules have been fabricated. Six of

Figure 4.1 Interconnect/Cell Level Test Vehicles

Interconnect Design No.	No. of Contacts	Contact Location	Contact Size	R_{Series}	Clean-ability	Strain Relief
1	1	Center	5/8		Good	NA
2	1	Center	1/2		Good	NA
3	1	Center	3/8		Good	NA
4	1	Center	1/4		Good	NA
5	3	Center	3/16		Good	No
6	3	Center	3/16		Excel	Yes
7	6	Center	50 x 75 Mils		Good	Yes
8	6	Center	50 x 75 Mils		Good	Yes
9	6	Center	50 x 75 Mils		Good	Yes
10	6	Center	50 x 75 Mils		Good	Yes
11	6	OutBoard	3/16		Excel	Yes
12	6	OutBoard	3/16		Excel	Yes
13	6	OutBoard	3/16		Excel	Yes
14	6	OutBoard	3/32 x 1/4		Excel	Yes
15	6	OutBoard	3/32 x 1/4		Excel	Yes
16	6	OutBoard	3/32 x 1/4		Excel	Yes

Figure 4.2 Interconnect Temp Shock Test Results: Cumulative No. of Cell Cracks

Interconnect Design No.	No. Shocks LN_2 - RT Alcohol (ΔT=220C)																								Comments
	1		2		4		6		8		10		15		20		25		30		40		50		
	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	
1a	2	M																							Massive Damage
2a	2	M																							Massive Damage
3a	1	3	M																						
4a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	0	5	
5a	2	4	M																						Massive Damage
6a	2	M																							Massive Damage
7a	0	0	0	0	0	0	0	0	1	0	1	0	1	0	2	0	2	0	2	0	2	0	2	0	
8a	0	0	0	0	0	0	0	0	1	0	1	0	1	0	2	0	4	0	5	0	7	0	9	0	
9a	1	0	1	0	1	0	1	0	0	0	1	0	1	0	2	0	3	0	7	0	8	0	9	0	
10a	0	0	2	2	3	3	3	3	M																Massive Damage
11a	3	3	3	3	4	4	5	4	5	4	5	4	5	5	5	5	M								Massive Damage
12a	1	0	1	0	2	0	2	0	2	0	2	0	2	0	3	0	4	1	6	1	6	2	M		
13a	4	3	4	3	4	3	5	5	5	5	5	5	5	5	5	5	M								Massive Damage
14a	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	2	0	2	1	3	1	3	3	
15a	1	0	2	0	2	0	2	0	2	0	2	0	2	0	3	0	3	1	4	1	6	2	6	3	
16a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	

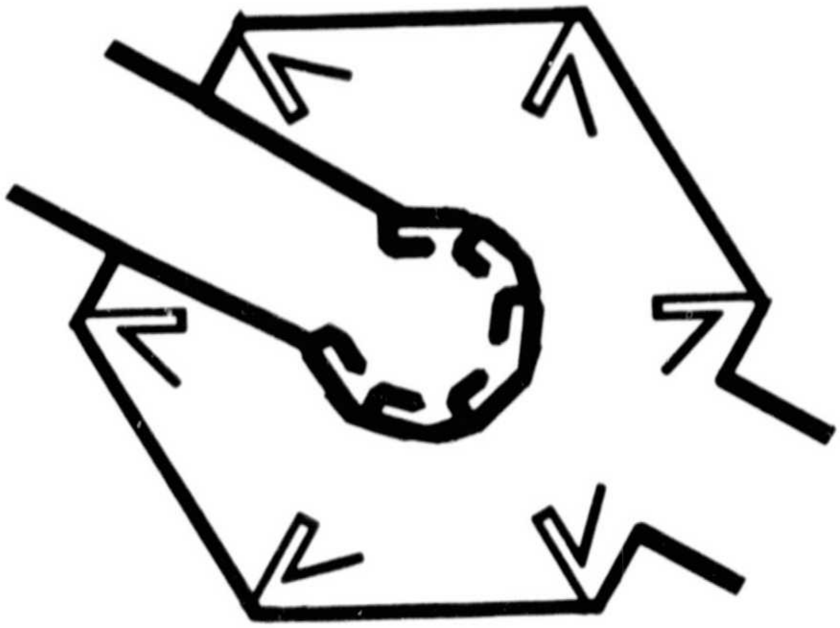

Figure 4.3 Multiple Back Contact Design Number 07

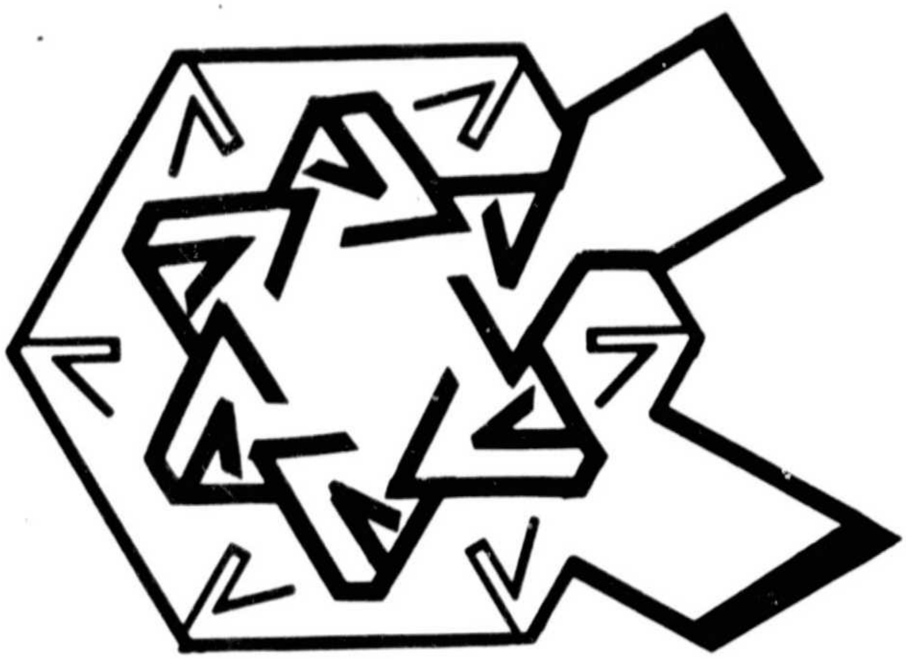

Figure 4.4 Multiple Back Contact Design Number 16

these have been subjected to thermal cycling at Motorola from -40C to +90C. Each of these six modules was visually inspected at 20X after solder reflow, encapsulation, and every 50 cycles of thermal testing. Figure 5.1 defines these test module configurations. Test results for these six modules are depicted in Figure 5.2. Note that these modules were fabricated for test purposes and not deliverable on this contract.

Thirteen of the contracted 24 modules were tested at Motorola, in two groups. Test results for the initial group of six all series modules, with single back contacts, are shown in Figure 5.3. Results of the remaining seven modules are shown in Figure 5.4.

The six all-series modules were electrically characterized before and after the qualifications tests outlined in JPL Specification 5-342-1 Rev. B. The modules peak output power degraded an average of [illegible].2% as a result of being subjected to the qualification test sequence. The average initial output power was 27.1 watts per module with a standard deviation of .72 watts. One module suffered an intermittent open circuit during humidity cycling. Initial diagnostic efforts indicated that the module was electrically good up to approximately 45C, and open circuit at higher temperatures.

6.0 Conclusions

Cell/interconnect temperature shock tests showed that two of the sixteen interconnect designs are capable of significantly reducing the probability of cell fracture, due to thermally induced deformations. These are design numbers 7 and 16. Thermal cycling of six experimental test modules show that the several encapsulation changes which were implemented do reduce the number of linear cell cracks and that multiple back contacts with strain relief (when

Figure 5.1 Module Level Test Vehicles

Module Design No.	Serial No.	Configuration										
		Pan	Gel	Spacers	Eval. Cycle	Kapton	Tooling	Cell Orient.	Interconnect Design			
1	50	Shallow	1.1	Yes	Long	No	New	No	1x48	- Folded 4-sides	5/8"	Single Back Contact
2	51	Shallow	1.1:1	Yes	Long	No	New	No	6x8	- Folded 2-sides	5/8"	Single Back Contact
3 Control #1	102	Deep	1.1:1	Yes	Long	No	New	No	4x12	- Folded 2-sides	5/8"	Single Back Contact
4 Control #2	100	Deep	1.1:1	Yes	Long	No	New	Yes	1x48	- Folded 2-sides	5/8"	Single Back Contact
5	101	Deep	1.1:1	Yes	Long	No	New	Yes	1x68	- Folded 2-sides	1/4,3/8, 1/2,5/8	Single Back Contac
6	103	Deep	1.1:1	Yes	Long	No	New	Yes	1x48	- Folded 2-Sides	3/16, Con. w/strain relief on ½ of cells	Tri B,

Figure 5.2 Module Temp Cycle Test Results: Cumulative No. of Cell Cracks

Module Design No.	Initial		50 cyc.		100 cyc.		150 cyc.		227 cyc.		-40 to +90C per MIL-STD-810B			
	L	C	L	C	L	C	L	C	L	C				
1	3	1	3	4	3	5	3	7	--	--				
2	2	0	2	1	2	4	2	5	2	5				
3	0	0	2	1	5*	1	5	1	5	1				
4	0	0	0	1	0	1	0	1	0	1				
5	0	0	0	1	0	1	0	1	0	1				
6	0	0	0	0	0	0	0	0	0	0				

*Glass was broken during transient and replaced.
It is unknown as to the exact damage due to repair.

Figure 5.3 5-342-1, Rev. B, Test Results
of the All-Series Group of Five Modules
with Single Back Contacts

Module Number	Initial Peak Power (Watts)	Final Peak Power (Watts)	% Power Change
02	26.25	26.79	+2.0%
04	27.72	26.80	-3.3%
06	27.54	26.35	-4.3%
012	26.44	26.62	-3.1%
011*	28.08	27.61	-1.7%
013	27.94	26.79	-4.1%

* NOTE: Module 011 electrically on an intermittent basis opened during humidity cycling.

Figure 5.4 Environmental Test Results of Series/Parallel Modules

Single Back Contact Modules

Module Series Number	Initial Power (Watts)	Final Power (Watts)	Δ Power %
630E	23.62	22.12	- 6.4%
631E	20.10	17.26	- 14.1%
632E	17.85	16.14	- 9.6%

Multiple Back Contact Module

Module Series Number	Initial Power (Watts)	Final Power (Watts)	Δ Power %
928E	28.12	27.08	- 3.7%
930E	27.81	26.79	- 3.7%
933E	27.58	26.89	- 2.5%
934E	28.53	27.50	- 3.6%

properly sized) can significantly reduce cell microcracks. In general, the developmental efforts on this contract have resulted in at least a 4 to 1 improvement in the resistance of the cell/interconnect subassembly to thermally induced microcracks; and have eliminated the concern associated with cell linear (crystalline axes) cracks.

7.0 Recommendations & Implementations

The following recommendations and implementations are:

- Multiple front and back solar cell contacts with adequate strain relief be utilized to minimize power degradation due to cell breakage.
- Solar cells be placed in the module such that their crystalline axes not coincide with interconnect and/or produce substrate material boundaries; i.e., copper etch pattern, substrate reinforcement ribbing.
- Encapsulation system be free of members that allow differential pressures to be built up within the module.

The last five test modules were fabricated with these changes and showed significant improvements. These modifications were subsequently introduced on production modules.

8.0 Module Costing

Module costing elements treated herein are component piece parts and assembly labor content. Costs of component parts are given in Figure 8.1 for production volumes of ten thousand modules. These costs vary with production volumes and tooling level. Figure 8.2 gives the labor content and associated cost information in terms of SAMICS input.

SAMICS Data

The following list of commodities was utilized in the preparation of SAMICS Format A's for the costing analysis. These commodities must be added to the SAMICS Cost Account Catalog.

Figure 8.1 Cost Account Catalog (Additions)

Catalog No.	Description	Units of Measure	Price/Unit
E1140D	Solar Cell	Units	$3.68
E1072D	Interconnect	Units	$9.40
E1160D	Panel Connector	Units	$2.30
E1528D	Pottant	Lbs.	$1.30
E1480D	Cover Glass	Units	$1.98
**	Pan & Bezel	Units	$7.34

FORMAT A

Figure 8.2

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1	Process [Referent]	Reflow
A2	[Descriptive Name]	Attach cells to interconnect

PART 1 – PRODUCT DESCRIPTION

A3	[Product Referent]	RFIC
A4	Descriptive Name [Product Name]	Interconnect
A5	Unit Of Measure [Product Units]	Interconnects

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	0.03	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	0.20	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.85	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	--		
A9a	Component [Descriptive Name] (Optional)	--		
A10	Base Year For Equipment Prices [Price Year]	1979		
A11	Purchase Price ($ Per Component) [Purchase Cost]	$3,000		
A12	Anticipated Useful Life (Years) [Useful Life]	3 yr.		
A13	[Salvage Value] ($ Per Component)	$200		
A14	[Removal and Installation Cost] ($/Component)	$500		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

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Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) Reflow

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	35	Sq. Ft.	Manufacturing Space
B3080D	3.68	PRSN* yrs	Module Assembler
B3736D	0.05	PRSN* yrs	Maintenance Mechanic II
B3336I	0.50	PRSN* yrs	Assembly Supervisor
B3320I	0.10	PRSN* yrs	Assembly Foreman
B3240B	0.25	PRSN* yrs	Mechanical Engineer

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
*E1140D	1.44	Units	Solar Cells
*E1072D	0.03	Units	Interconnect
C1032B	1.0	KW-hr.	Electricity
C2128B	100	Cu-ft	Ventilation

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
Cells	0.020	Interconnect cell	Interconnect

Prepared by *Bruce Larson* Date *12-27-78*

REVERSE SIDE JPL 3037-S R 7/78

FORMAT A

Figure 8.2 (continued)

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1	Process [Referent]	Encapsulation			
A2	[Descriptive Name]	Encapsulation and Framing			

PART 1 – PRODUCT DESCRIPTION

A3	[Product Referent]	ECP			
A4	Descriptive Name [Product Name]	Module			
A5	Unit Of Measure [Product Units]	Module			

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	0.016	Units (given on line A5) Per Operating Minute		
A7	Average Time at Station [Processing Time]	0.10	Calendar Minutes (Used only to compute in-process inventory)		
A8	Machine "Up" Time Fraction [Usage Fraction]	0.90	Operating Minutes Per Minute		

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	--			
A9a	Component [Descriptive Name] (Optional)	--			
A10	Base Year For Equipment Prices [Price Year]	1979			
A11	Purchase Price ($ Per Component) [Purchase Cost]	$14,000			
A12	Anticipated Useful Life (Years) [Useful Life]	3 yr.			
A13	[Salvage Value] ($ Per Component)	$1,000			
A14	[Removal and Installation Cost] ($/Component)	$2,000			

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) Encapsulation

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	200	Sq. Ft.	Manufacturing Space
B3080D	1.95	PRSN* yrs	Module Assembler
B3736D	0.03	PRSN* yrs	Maintenance Mechanic II
B3336I	0.25	PRSN* yrs	Assembly Supervisor
B3320I	0.03	PRSN* yrs	Assembly Foreman
B3240B	0.04	PRSN* yrs	Mechanical Engineer

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
*E1160D	0.16	Units	Panel Connector
*E1528D	0.10	lbs	Pottant
*E1480D	0.16	Units	Cover Glass
**	0.16	Units	Pan & Bezel
C1032B	1.0	KW-hr	Electricity
C2128B	100	Cu-ft.	Ventilation

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
Interconnects	1.0	Module	Interconnect Modules

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FORMAT A

Figure 8.2 (continued)

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1	Process [Referent]	Test
A2	[Descriptive Name]	Module Test and Acceptance

PART 1 – PRODUCT DESCRIPTION

A3	[Product Referent]	TMOD
A4	Descriptive Name [Product Name]	Tested Module
A5	Unit Of Measure [Product Units]	Modules

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	0.5	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	0.7	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.85	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	--		
A9a	Component [Descriptive Name] (Optional)	--		
A10	Base Year For Equipment Prices [Price Year]	1979		
A11	Purchase Price ($ Per Component) [Purchase Cost]	$80,000		
A12	Anticipated Useful Life (Years) [Useful Life]	5 yr.		
A13	[Salvage Value] ($ Per Component)	$16,000		
A14	[Removal and Installation Cost] ($/Component)	$12,000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

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Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) Test

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) **OR PER MACHINE PER SHIFT** (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	200	Sq. ft.	Manufacturing Space
B3768D	8.25	PRSN* yrs	Module Tester
B3688D	0.25	PRSN* yrs	Electronic Maintenance
B3336I	0.50	PRSN* yrs	Operations Supervisor
B3320I	0.25	PRSN* yrs	Foreman
B3208B	0.3	PRSN* yrs.	Electrical Engineer

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	1.5	KW-hr	Electricity

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
Modules	0.98	Modules / Modules	Modules

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